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The Kinematics of the Lag-Luminosity Relationship

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The Kinematics of the Lag-Luminosity Relationship

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Abstract. Herein I review the argument that kinematics, i.e. relativistic motions of the emitting source in gamma-ray bursts (GRBs), are the cause of the lag-luminosity relationship observed in bursts with known redshifts.

INTRODUCTION

Norris *et al.* [1] have discovered a relationship between the peak luminosity of gamma-ray bursts (GRB) and the pulse time lag between BATSE energy channels. In Salmonson 2000 [2] this correlation was shown to be improved when we neglect our poor knowledge of received photon energy. Thus instead we use the correlation between photon number luminosity and pulse time lag. It was found that the inferred isotropic peak number luminosity N_{pk} (photons s^{-1}) is related to the observed spectral lag between energy channels Δt by

$$N_{pk} = 8.6 \times 10^{56} \Delta t^{-0.98} \ . \tag{1}$$

I argue that kinematics are the origin of this relation [2]. Specifically, bursts with emitting material moving with a higher velocity toward the observer appear more luminous and have shorter observed lags (derived from an intrinsic pulse cooling timescale) between observed energy channels due to relativistic blue shift. Relativistic beaming allows one to only consider emitters moving directly toward the observer. I propose that the wide range of observed (cosmological redshift compensated) spectral lags and inferred luminosities (see Figure 1) can be explained if GRBs derive from a relativistic jet, with opening angle θ_0, in which the fastest material moves along the core of the jet and the velocity of the material monotonically decreases with increasing angle from the jet axis. The variety of observed bursts then derives from our perspective of the jet. All of the material is presumed to move relativistically ($\gamma \gg 1$) and so all of our received flux is derived from a very small $\sim 1/\gamma^2$ solid angle of the jet; much smaller than the jet opening angle ($1/\gamma \ll \theta_0$). It is from this small region that all of our information about a burst is derived.

This hypothesis that all GRBs derive from a single jet morphology viewed at various orientations then predicts that there will be GRB jets viewed at such high inclinations, and thus with such low Lorentz factors that the relativistic beaming angle will be larger than the jet opening angle ($1/\gamma > \theta_0$). The emission will no longer be consistent with isotropy and thus I predict a break in the lag-luminosity relation: $N_{pk} \propto \Delta t^{-3}$ [3]. Due to the low Lorentz factor, such bursts would be very dim. If GRB980425, which was unusual in several respects [3] and, by its association with supernova 1998bw [4], was sub-luminous, defines this break (see Figure 1), then one can calculate key features of the GRB jet. In particular, Lorentz factors range from $\gamma_{\rm max} \sim 1000$ for bright bursts such as GRB990123, to $\gamma_{\rm break} \sim 100$ for more middling bursts like GRB980703. The position of the break implies an opening angle of $\theta_0 \sim 1°$ and thus a total gamma-ray burst energy of $E_{\rm tot} \sim 10^{50}$ ergs, which is much less than isotropic energy estimates (up to 10^{54} ergs [5]).

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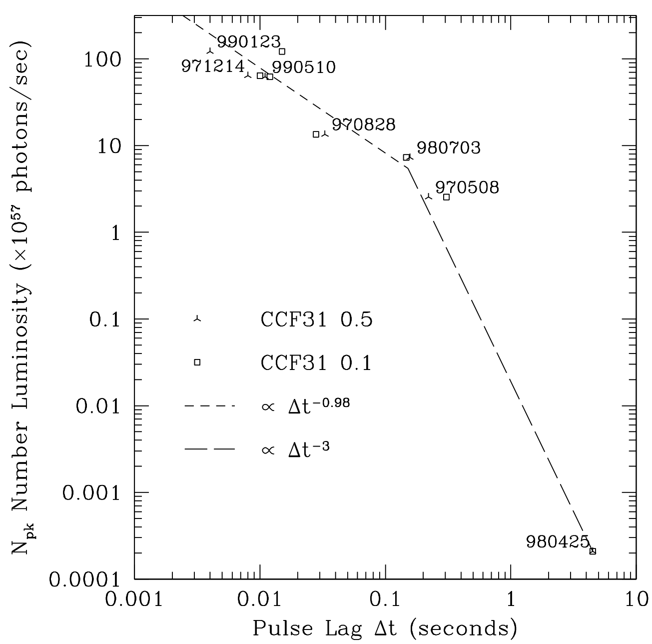

FIGURE 1. Peak photon number luminosity N_{pk} versus spectral pulse lag for six bursts with known redshifts plus GRB980425. A break is inferred by fitting a break slope $\propto \Delta t^{-3}$ to intersect GRB980425. Spectral cross-correlation function lags between BATSE channels 3 and 1 (CCF31) for regions down to 0.5 and 0.1 of peak intensity were obtained from Norris *et al.* (2000). The line of best fit for 0.1 (squares) is $\propto \Delta t^{-0.98}$.

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